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ABSTRACT

Metascientific education of prospective science teachers is seen as a priority in many European countries, in accordance with the central role that contents about the nature of science have achieved in national curricula. In this paper, we present an original theoretical tool, which we have called the matrix of stages and strands that may prove of help in adapting or designing didactical activities with the aim of teaching the philosophy of science to science teachers. The matrix arranges a collection of the most important theoretical models that philosophers of science have advanced during the twentieth century around six central topics of their discipline. This didactical tool that we present is related to the general rationale of our work with prospective teachers, which aims to answer three fundamental research questions, those regarding the selection, coherence and functionality of the philosophy of science in science teacher education. We exemplify our rationale through an original didactical activity that we have designed and implemented; this activity involves the use of the matrix.
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The philosophy of science in prospective science teacher education. Rationale and practical proposals.

Abstract

Metascientific education of prospective science teachers is seen as a priority in many European countries, in accordance with the central role that contents about the nature of science have achieved in national curricula. In this paper, we present an original theoretical tool, which we have called the *matrix of stages and strands*, that may prove of help in adapting or designing didactical activities with the aim of teaching the philosophy of science to science teachers. The matrix arranges a collection of the most important theoretical models that philosophers of science have advanced during the twentieth century around six central topics of their discipline. This didactical tool that we present is related to the general rationale of our work with prospective teachers, which aims to answer three fundamental research questions, those regarding the selection, coherence and functionality of the philosophy of science in science teacher education. We exemplify our rationale through an original didactical activity that we have designed and implemented; this activity involves the use of the matrix.

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Introduction

Metascientific contents, or contents about the *nature of science* (NOS), constitute a central component of recent science curricula for compulsory education in many European countries (McComas, 1998b; Millar and Osborne, 1998; Matthews, 2000). The need for the introduction of the metasciences (philosophy, history and sociology of science) in the school science curriculum has been consistently advocated in the literature of didactics of science during the last fifteen years (Duschl, 1990; Matthews, 1994, 1998; McComas, 1998b). Among these metasciences, the philosophy of science is recognised by scholars as the key contribution to the transformation of science education for the twenty-first century, in accordance with the ambitious aims that have been proclaimed for scientific literacy (Millar, 1989; Duschl, 1990; Driver et al., 1996; McComas and Olson, 1998; Millar and Osborne, 1998).

It is assumed within didactics of science that knowledge of selected topics from the philosophy of science, such as *evidence*, *method* or *explanation*, will help citizens to make well-informed and critical decisions about important scientific and technological issues in democratic societies. Thus, there is consensus that it is necessary for the scientifically literate citizen of the twenty-first century not only to know science but also to know *about* science: how it is created and validated, how it evolves through history, and how it relates to the social and cultural milieu. As the British report *Beyond 2000* puts it,

young people need an understanding of how scientific inquiry is conducted – to help them appreciate the reasoning which underpins scientific knowledge claims, so that they are better able to appreciate both the strengths and the limitations of such claims, in a range of situations and contexts. (Millar and Osborne, 1998: 11-12)

Universal recognition of the key importance of the philosophy of science in general science education naturally generates the urgent need for a strong philosophical education of science teachers, especially focussing on the pre-service stage of teachers who will work at the secondary level (McComas, 1998b). In response to the acknowledgement of this need, several theoretical and practical proposals have been advanced within current didactics of science. These proposals integrate in different ways the philosophy of science both in pre- and in-service science teacher education courses (Jiménez Aleixandre, 1995; Boersema, 1998; Loving, 1998; McComas, 1998a; Nott and Wellington, 1998; Izquierdo, 2000; Adúriz-Bravo, in press-a).

Historically, contents from the philosophy of science have been considered as a powerful auxiliary tool for science teaching (Matthews, 1994, 1998). That is, strong *instrumental* goals have been advocated for the philosophy of science in science teacher education. In addition to this, the philosophy of science may be regarded as a strategic field within science teachers' professional knowledge (Bromme and Tillema, 1995), with a powerful *metacognitive* status, and capable of influencing other fields, such as teachers' ideas on teaching and learning science. Hence the interest that didactics of science has shown in conducting research on teachers' ideas on the nature of science and issuing proposals to improve those ideas (Lederman, 1992; McComas, 1998b; Adúriz-Bravo et al., in press).

Taking this general setting into account, we have focussed for some time now on the

critical examination of the available proposals regarding the integration of the philosophy of science in science teacher education. We have studied this integration by means of a theoretical framework that has allowed us to classify and assess the available proposals (Adúriz-Bravo et al., 2001; Adúriz-Bravo, in press-b). In this paper, we are going to present a particular tool that appeared as an outcome of this framework and has several didactical implications. We have called this tool the *matrix of stages and strands from the philosophy of science*. The matrix collects different theoretical models that philosophers of science have constructed during the twentieth century around six central philosophical topics, roughly identifiable with epistemology, ontology, methodology, axiology, evolution and recursion.

This tool, originally intended for the analysis of our collection of proposals, may be of use in designing further didactical activities to teach selected contents from the philosophy of science to science teachers. We will support this claim through presenting an example of the application of our ideas.

Our tool is inscribed within a general rationale that provides the guidelines and foundations for our work regarding science teacher education in the philosophy of science. This rationale aims at attacking some of the several theoretical and practical problems that appear in this new and complex field. In particular, our rationale deals with three core questions that may guide debate, research and innovation:

1. *Selection*. What philosophy of science should be taught to science teachers?
2. *Coherence*. What didactical methodologies are most appropriate in order to teach it?
3. *Functionality*. What relationships should be established in teacher education between science, philosophy of science, and didactics of science?

Prior knowledge

Science education and didactics of science, that is, the practice of teaching science at school and the scholarly discipline reflecting on this practice, have had a development that was until recently very scarcely related to the philosophy of science and to other metasciences. This situation was portrayed by Richard Duschl (1985) as a 'mutually exclusive development' of the two fields. Theoretical rationales and practical proposals in science education are even nowadays mainly informed by educational and psychological research, largely disregarding ideas coming from the disciplines that study the nature and evolution of science. In the last fifteen years, however, this tendency is increasingly being reverted; there has been an integration of the fields of science education and the philosophy of science through the work of scholars such as Richard Duschl, Derek Hodson, Norman Lederman, Michael Matthews and William McComas (Matthews, 1998).

The study of the different relationships between the philosophy of science and science education constitutes today an expanding area of interest within didactics of science, known by the acronym HPS (history and philosophy of science for science teaching). This area comprises several very active research lines, such as mental models and conceptual change (Nersessian, 1992), ideas on the nature of science (McComas, 1998b), use of historical case studies (Duschl, 1990; Monk and Osborne, 1997), debate around the status of constructivism (Matthews, 1994; Osborne, 1996), and epistemological analyses of the discipline of didactics of science (Adúriz-Bravo, 1999). These research lines involve the use of different models drawn from the philosophy of

science; the adaptations made to these models have proved sometimes to be insufficient or defective, lagging thirty years behind current philosophical debates (Jiménez Aleixandre, 1997; Adúriz-Bravo, 1999). As research and development informed by this oversimplified or outdated philosophy of science permeate into science educational practice, it can be expected that some science curricula, instructional materials, and science teacher education courses show an incomplete or inadequate philosophical component.

In addition to this, there is an enormous amount of evidence showing that prospective and in-service science teachers often lack an adequate view of the nature of science (Koulaidis and Ogborn, 1989; McComas et al., 1998; Adúriz-Bravo et al., in press). Science teachers' naive epistemological images are generally found to be similar to those developed by the philosophical school of *logical positivism* during the first half of the twentieth century. It has been suggested that these insufficient or incorrect ideas affect teachers' classroom behaviour and negatively influence their students' images of science (Lederman, 1992).

These are powerful reasons supporting the need to closely inspect the education of science teachers in the philosophy of science. We confer high priority to the study and discussion of this issue, taking into account that *the nature of science forms the core of future citizens' scientific literacy*. We have been carrying on an attempt of critical inspection of the issue by analysing some of the available proposals to teach the philosophy of science that have been advanced within didactics of science. We have collected over sixty of these proposals to form the data base of our study.

In order to assess these proposals, we have developed a new theoretical framework (Adúriz-Bravo, in press-b; Adúriz-Bravo et al., 2001) with thirteen analytical dimensions: five dimensions giving factual information on the proposals; four dimensions that respond to curricular questions, helping to put the proposal into context; and four dimensions regarding the specific philosophical contents of the proposals.

Our framework, in spite of its original analytical nature, has resulted in the creation of several didactical tools that help us in our work of prospective science teacher education in the philosophy of science. We have selected one of these tools, the matrix of strands and stages, to develop our theoretical ideas in this paper.

Background of this paper

Empirical background

Our general rationale was constructed using the input of several prospective secondary science teacher education initiatives in which we have participated during the last three years. Both authors of this paper have been consistently concerned with the philosophical education, at pre- and in-service stages, of science teachers for the different educational levels from kindergarten to university, both in Spain and Argentina (Adúriz-Bravo, in press-b; Adúriz-Bravo et al., 2001; Izquierdo, 2000).

In particular, the matrix that we present in this paper has been empirically validated through the implementation of a didactical activity (Adúriz-Bravo, in press-a). This activity uses a detective story, in book and film format, in order to teach some

philosophical topics related to the process of scientific explanation. We will present a summary of this activity as a practical proposal that exemplifies our ideas.

Theoretical background

During these years of work with teachers, we have been developing a general theoretical framework that provides the rationale to give in principle an answer to the three fundamental questions stated above. This framework makes extensive use of two analytical tools originally designed by the first author. These tools are a periodisation of the schools that appeared in the twentieth-century philosophy of science, which we call *stages*, and an identification of the main theoretical topics of this discipline, which we call *strands*.

Stages and strands are just one of the elements of our framework, details on the complete picture can be found in Adúriz-Bravo et al. (2001). We have selected these two constructs because they constitute the basis of the so-called matrix.

Stages

We have divided the history of twentieth-century philosophy of science in three overlapping periods, the *stages*. These are the periods of the philosophy of science that the proposals from our collection select to teach, and use as a source for their activities. Our scheme can also be used with didactical purposes, as it provides a dynamic picture of the development of this discipline.

For the sake of concision, we will present the stages only very briefly. More information on the history of the philosophy of science in the twentieth century can be found in Estany (1993) and Giere (1988).

Logical positivism and received view

This first stage roughly covers from 1920 to 1970. The constitution of the Vienna Circle in the period between wars is considered the starting point for our identification of the relevant contents from the philosophy of science. The demise of the so-called received view around 1970 shows the end of this period. This first *analytical* approach to the philosophy of science is mainly *syntactic*, and draws heavily from formal logic.

Critical rationalism and the new philosophy of science

This second stage goes from 1935 to 1990. It starts with the early critiques to logical positivism issued in France and Germany, and ends when the sociology of science definitely absorbs the *externalist* perspective introduced by Kuhn (1970).

Several different schools within this stage may be united because of their profound rebuttal of the theses of logical positivism and their introduction of external (i.e. historical and social) considerations.

Postmodernism and contemporary views

This third stage starts with Paul Feyerabend's radical statements about science in the

early 1970s and goes on to the naturalised philosophy of science of the late 1990s. This last stage represents a return to classical philosophical questions, revisited with new conceptual tools, such as the concept of *theoretical model* (Giere, 1988).

Strands

This construct is designed in order to identify the main concepts from the philosophy of science that are addressed in the proposals for science teacher education (Adúriz-Bravo, in press-b). The construct draws from models for science curriculum design that have successfully used the so-called *structuring ideas* (Sanmartí and Izquierdo, 1997). These ideas structure scientific disciplines and permit to organise different theoretical models around them; in this sense, structuring ideas work as keystones of the science curriculum architectonics.

We have imported this design idea to apply it to the teaching of the philosophy of science. In order to analyse the contents from the philosophy of science in the proposals that we have collected, we have developed six sets of structuring ideas; we have called them *strands*. These strands organise the philosophical concepts, models, sources and activities that can be identified within the proposals. We will very briefly elaborate on the strands; more detailed information can be found in other references (Adúriz-Bravo, in press-b; Adúriz-Bravo, Izquierdo and Estany, 2001).

Correspondence and rationality

This first strand comprises two main aspects of scientific knowledge: the way in which it is believed that theoretical entities and reality fit, and the rational criteria that scientists use to assess this fitting. These two questions have been in the foundations of the philosophy of science since its earliest stages.

Regarding the first matter, several different units of epistemological analysis have been proposed (concepts, models, theories), and two main opposite philosophical views –*realism* and *instrumentalism*– have been advocated to map these units onto the real world. These two broad views of correspondence have used specific constructs to explain the relationships between theoretical and observational terms (Hempel, 1966). As to the second aspect, traditional philosophers were concerned with the logical structure of scientific judgement; this approach is called *hard* rationality. It was only with the new philosophy of science in the 1960s that *external* (social and historical) factors were incorporated into the analysis of theoretical choices (Kuhn, 1970).

Representation and languages

This strand concerns the different structural units that philosophers of science have produced in order to account for the process of representation of the natural world. Traditional analyses are theory-based, assuming that theories are at the top of the scientific hierarchy, and that formal disciplines achieve maturity when axiomatically organised. The current *model based view*, derived from a semantic conception of scientific knowledge, challenges this excessively formalist approach (Giere, 1988).

Theories and models as abstract entities are characterised by linguistic propositions that make them communicable, especially through textbooks. This fact has generated the

need for a study of scientific language both from traditional discourse analysis and from the new perspective of *rhetoric* (Newton et al., 1999).

Intervention and method

This strand includes the classical neo-positivistic account of a unique, well-defined scientific method that precedes research and comprises a fixed series of steps, starting from observation and ascending to scientific laws. Several variations to this scheme have been proposed since the 1930s, including Popper's (1963) very elaborate *falsificationism*. Among recent contributions to the discussion, we highlight methodological models that focus on the construction of paradigmatic experimental facts through writing (Izquierdo, 1994); these models partly stem from the new sociology of science and are of great interest for didactics of science.

Contexts and values

This strand regards the relationship between science and the general social, cultural and educational contexts, which are characterised by their own aims and values. Traditional accounts have disregarded such relationships advocating a strong *neutrality* for science. Science was portrayed as a value-independent activity aimed at the discovery of truths about the world that are of value by themselves, independent of their use, sources, power and consequences. More recent views on the social nature of science frontally challenge these assumptions; philosophers add to the classical contexts of discovery and justification those of innovation and education, proposing an *axiological* study of the scientific endeavour (Estany, 1993).

Evolution and judgement

This strand involves a diachronic study of the theoretical entities that constitute the core of science. The traditional philosophy of science sketched a rather static picture of the scientific enterprise, producing a cumulative view that disregarded the study of the mechanisms of *conceptual change*. New models, following Kuhn's (1970) account of scientific revolutions, focus on the nature of knowledge shifts. Another aspect of interest to analyse scientific evolution is the study of the ways in which scientists make reasonable choices between competing explanations. In this issue, the contributions of the cognitive philosophy of science (Giere, 1988) are of the utmost relevance, as they propose a *naturalised* approach to the concept of rationality.

Normativity and recursion

This last strand focuses on the recursive, metadiscursive nature of the philosophy of science, that is, on the fact that the discipline is a second order discourse theorising about science that can turn onto itself to perform a self-analysis of its own validity and reach (Estany, 1993). This so-called *metaphilosophical* analysis permits to distinguish between a strongly normative approach to the discipline, in which general a priori parameters are sought, and an explanatory approach, considering the philosophy of science as another empirical discipline.

The matrix

Our tool is a two-dimensional array of the strands and stages mentioned before. The matrix collects the main models that the three periods of the twentieth-century philosophy of science generated for each of the six structuring topic (figure 1).

	<i>Logical positivism Received view</i>	<i>Critical rationalism New philosophy of science</i>	<i>Postmodernism Contemporary views</i>
<i>Correspondence Rationality</i>	Representational realism Hard rationalism	Instrumentalism Irrationalism	Pragmatic realism Moderate rationalism
<i>Representation Languages</i>	Theory-based view	Paradigm-based view	Model-based view
<i>Intervention Method</i>	Unionism		Secessionism Praxeology
<i>Context Values</i>	Objectivity	Contextualism	Axiology
<i>Evolution Judgement</i>	Cumulative view	Revolutionary view	Evolutionary view
<i>Normativity Recursion</i>	Strong normativity		Anarchy Naturalism

Figure 1. The matrix of stages and strands from the philosophy of science. Only a few philosophical models are shown.

A practical proposal

As we have said, we have collected over sixty proposals, elaborated by several authors, which were designed to teach the philosophy of science to prospective and in-service science teachers. Some of these proposals may be taken as *paradigmatic examples* (Izquierdo, 2000) of our rationale and provide practical contexts where we can assess our ideas. In this sense, we have adapted them in our work. Such proposals include a wide range of didactical strategies, such as the use of comics, films, dramatisations and novels.

Many of these proposals are directed to the improvement of the teaching of various scientific contents (Abd-el-Khalick and Lederman, 1999), but we are here concentrating only on the aim of teaching the philosophy of science per se, independent of such derivations.

We will now present a proposal that we have designed for the purpose of teacher education in specific topics of the philosophy of science, showing explicitly how it uses the matrix. The proposal is centred on the first three strands, which provide a model of scientific explanation.

Scientific reasoning and detective novels

This didactical unit (Adúriz-Bravo, in press-a) is aimed at the teaching of a set of central concepts from twentieth-century philosophy of science, such as *explanation*, *reasoning*

and *inference*, that are considered important within science education (Duschl, 1990; Newton et al., 1999). This is done by using a world-famous detective novel, Agatha Christie's *Death on the Nile*, in book and film format.

We oppose Christie's construction of the narrative (by means of deductive reasoning) to Hercule Poirot's solution of the criminal enigma, which draws heavily on *abductive* patterns. Classical logic, modelling, and the role of reasoning and creativity in scientific discovery are examined through paper-and-pencil tasks and small group discussion.

Models of *correspondence* from stages 1 and 3 are constantly opposed using an analogy that compares detective investigation and scientific inquiry; the syntactic approach, typically developed by logical positivism, is compared to the semantic approach, characteristic of contemporary schools such as the cognitive philosophy of science. The opposition between these models is achieved through the analysis of three kinds of inferences: deduction, induction and abduction.

Traditional philosophy of science has concentrated on the opposition between inductive and deductive reasoning, combining both in the *Aristotelian method* (Hempel, 1966), which is in the base of many well-known introductions to the nature of science in textbooks and courses. Abduction as a logical mechanism for scientific explanation has been largely disregarded in the philosophy of science and in science education, but it is currently recognised as a core element in the process of scientific modelling (Giere, 1988; Thagard, 1992) that should be taught at school. This proposal recovers abductive reasoning as a powerful formal analogy of the process of modelling.

With the emergence of a semantic conception of theories within the philosophy of science in the last thirty years, a *model based view* was developed (Giere, 1988), and subsequently moved to the areas of cognitive science and didactics of science (Duschl, 1990). This philosophical approach is interested in how theories are produced and selected, how they make sense to scientists, and how they are used and learnt, rather than in their mere formal structure of deductively concatenated axioms. Within this conception, models are the key entities of theoretical thinking; scientific modelling can be regarded as a process of abduction from theory-laden evidence to abstract theoretical organisations (Giere, 1988; Thagard, 1992).

This proposal has adapted original sources from philosophy of science (among others: Samaja, 1994), a procedure that is yet uncommon in science education but that has been heavily recommended (McComas, 1998). These sources are introduced together with their application to the narrative, in order to effectively anchor the analogical process. We will present here a sketch of the proposal with its main features. The activity begins by exploring the structure of classical detective novels in terms of its key elements: crime, suspects, clues, investigation.

A first approach to the formal structures of Hercule Poirot's solution to the mystery and Agatha Christie's construction of the plot is asked from teachers. Later on, formal argumentation patterns for the three main kinds of inferences are presented; here we use Samaja's (1994) Spanish version of Charles Sanders Peirce's (1967) canonical presentation, as follows:

* Three statements are considered: *p*. All the beans from this bag are white; *q*. These beans are white; and *r*. These beans are from this bag.

* These statements are combined in the following three inferential patterns: *I*. If p and r , then q ; *II*. If q and r , then p ; *III*. If p and q , then r . Pattern *I* is called deduction, pattern *II* is called induction, and pattern *III* is called abduction. Abduction can also be structured in the form of a categorical syllogism, in which the if-clause is called by Paul Thagard (1992) a *rule*.

Instances for the three ways of reasoning are extracted from the book, and with this framework, the author's and the character's procedures are opposed: abduction is presented as a "reverse" deductive mechanism, or an ascending inference starting from incomplete evidence. The instructional unit ends with the transposition of these content-free apparatus to specific examples from science; among these, we have used the relationship between evidence and models in the fields of atomic structure and interior of the Earth.

Concluding remarks

This paper is based on the acknowledgement that the philosophy of science is a fundamental component of future citizens' scientific literacy, and consequently must be urgently infused into secondary science teacher education. Current programmes at the pre-service stage show several shortcomings in their philosophical component; the theoretical tool that we have presented intends to help in the improvement of such programmes.

Our general theoretical framework is enhanced when combined with other models to identify key issues in the philosophy of science and to evaluate proposals to teach them (for instance, Loving, 1998; Abd-el-Khalick and Lederman, 1999). We have found that the matrix of stages and strands may work as a very powerful didactical tool, as it provides science teachers with an extensive overview of the philosophy of science that makes it more meaningful, and allows them to seize the relevance and usefulness of philosophical contents for their professional development and for the preparation of future citizens. In science teacher education, strands also help us do a *pragmatic* selection of contents from the philosophy of science that is informed by didactics of science, and combines elements from competing research lines.

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